# High-power terahertz lasers with excellent beam quality for local oscillator sources

Completed Technology Project (2016 - 2018)

## Project Introduction

Many molecular species that compose the interstellar medium have strong spectral features in the 2-5 THz range, and heterodyne spectroscopy is required to obtain ~km/s velocity resolution to resolve their complicated lineshapes and disentangle them from the background. Understanding the kinetics and energetics within the gas clouds of the interstellar medium is critical to understanding star formation processes and validating theories of galactic evolution. Herschel Observatory's heterodyne HIFI instrument provided several years of high-spectral-resolution measurements of the interstellar medium, although only up to 1.9 THz. The next frontier for heterodyne spectroscopy is the 2-6 THz region. However, development of heterodyne receivers above 2 THz has been severely hindered by a lack of convenient coherent sources of sufficient power to serve as local oscillators (LOs). The recently developed quantum-cascade (QC) lasers are emerging as candidates for LOs in the 1.5-5 THz range. The current generation of single-mode THz QC-lasers can provide a few milliwatts of power in a directive beam, and will be sufficient to pump single pixels and small-format heterodyne arrays (~10 elements). This proposal looks beyond the state-of-the-art, to the development of large format heterodyne arrays which contain on the order of 100-1000 elements. LO powers on the order of 10-100 mW delivered in a high-quality Gaussian beam will be needed to pump the mixer array – not only because of the microwatt mixer power requirement, but to account for large anticipated losses in LO coupling and distribution. Large format heterodyne array instruments are attractive for a dramatic speedup of mapping of the interstellar medium, particularly on airborne platforms such as the Stratospheric Observatory for Infrared Astronomy (SOFIA), and on long duration balloon platforms such as the Stratospheric Terahertz Observatory (STO), where observation time is limited. The research goal of this proposal is to demonstrate a new concept for terahertz quantum-cascade (QC) lasers designed to deliver scalable continuous-wave output power in the range of 10 to 100 mW or more in a near-diffraction limited output beam: a chip-scale THz quantum-cascade vertical-external-cavity-surface-emitting-laser (QC-VECSEL). We focus here on the development of a chip-scale version of size < 1 cm3 that oscillates in a single mode and can readily fit on a cold stage. The enabling technology for this proposed laser is an active metasurface reflector, which is comprised of a sparse array of antenna-coupled THz QC-laser sub-cavities. The metasurface reflector is part of the laser cavity such that multiple THz QC-laser sub-cavities are locked to a high-quality-factor cavity mode, which allows for scalable power combining with a favorable geometry for thermal dissipation and continuous-wave operation. We propose an integrated design, modeling, and experimental approach to design, fabricate, and characterize amplifying reflective QC metasurfaces and QC-VECSEL lasers. Demonstration laser devices will be developed at 2.7 THz and 4.7 THz, near the important frequencies for HD at 2.675 THz (for measurements of the hydrogen deuterium ratio and probing past star formation), and OI at 4.745 THz (a major coolant for photo-dissociation regions in giant molecular clouds).


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## Table of Contents



## Organizational Responsibility

**Responsible Mission Directorate:**

Science Mission Directorate (SMD)

**Responsible Program:**

Astrophysics Research and Analysis

Astrophysics Research And Analysis

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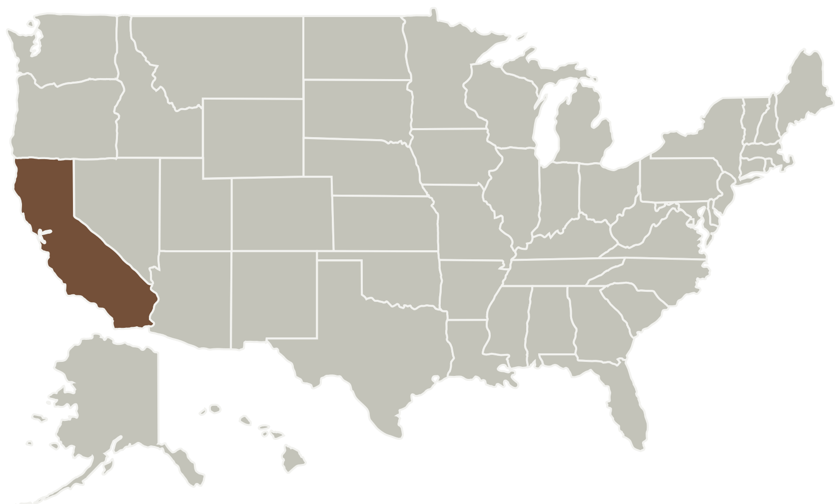
High resolution frequency measurements will be performed on a demonstration device at 2.7 THz will using downconversion with a Schottky diode sub-harmonic mixer to characterize the spectral purity, linewidth, and fine frequency tuning of this new type of QC-laser. This proposed laser is supporting technology for next-generation terahertz detectors.

### Primary U.S. Work Locations and Key Partners



| Organizations Performing Work | Role | Type | Location |
|---|---|---|---|
| University of Southern California(USC) | Supporting Organization | Academia<br>Asian American Native American Pacific Islander (AANAPISI) | Los Angeles, California |

| Primary U.S. Work Locations |
|---|
| California |

## Project Management

**Program Director:**
Michael A Garcia

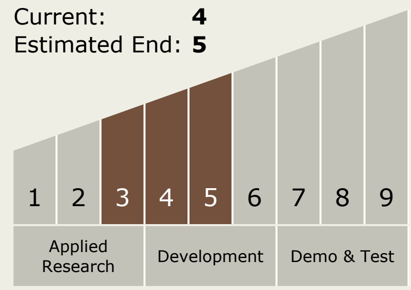
**Program Manager:**
Dominic J Benford

**Principal Investigator:**
Benjamin S Williams

**Co-Investigators:**
Shauna Huntsman
Erich Schlecht

## Technology Maturity (TRL)

Start: **3**
Current: **4**
Estimated End: **5**




## Technology Areas

**Primary:**

- TX08 Sensors and Instruments
  └ TX08.1 Remote Sensing Instruments/Sensors
    └ TX08.1.5 Lasers

## Target Destination

Outside the Solar System